An Analysis of Concept Learning: Simple Conceptual Control and Definition-Based Conceptual Control

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Concept learning can involve either contingency shaping of stimulus-class discriminations or the application of definitions of the concepts. Experimental behavior analysts have studied contingency shaping, whereas educational psychologists have studied definitional concept training. In this paper, we analyze definition-based concept learning in terms of stimulus-response chains. Then we apply this chaining analysis to principles of instruction proposed by educational psychologists. These principles include (a) stating the definition in terms of critical and variable attributes, (b) using examples and nonexamples, (c) using a rational set of examples and nonexamples, (d) presenting coordinate concepts simultaneously, and (e) presenting the next instance based on the learner's previous error.

There have been several behavior-analytic based theoretical analyses of "cognitive" behavior. For example, Hayes proposed a relational control theory relevant to semantics (Hayes, 1991, 1994); Palmer (1991) presented a behavior-analytic model of memory; and many researchers have discussed how descriptions of contingencies (i.e., rules) control behavior (e.g., Cerutti, 1989; Malott, 1989; Schlinger, 1993; Skinner, 1957). Most of these analyses suggest that we can interpret cognitive behavior in terms of the basic principles without using hypothetical constructs such as meanings and memory.

In keeping with these analyses, the present paper provides a behavior-analytic interpretation of the process of learning complex concepts as an alternative to a cognitive interpretation. While reviewing the literature on the teaching of concepts, we found the instructional use of definitions to be critical in learning complex concepts. The learning process involving verbal definitions differs considerably from that involving no verbal behavior. And often, complex concepts are learned through verbal mediation of the learner. However, experimental data from which the principles of instructional design were derived are usually interpreted using hypothetical cognitive processes and entities such as prototype development (Tennyson, Chao, & Youngers, 1981; Tennyson, Youngers, & Suebsonthi, 1983), concept mapping (Hirumi & Bowers, 1991; Schmid, 1990), levels of processes (Kunen, Cohen, & Slman, 1981), and structured knowledge (Stanners, Brown, Price, & Holmes, 1983). To the extent that concept

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learning based on definitions is a viable procedure, we should attempt to understand this procedure in terms of underlying behavioral processes.

In what follows, we (a) distinguish between simple concept learning and concept learning involving definitions, (b) analyze the role of definitions in producing conceptual discriminations in learners, and finally, (c) review the principles of instruction in terms of basic behavioral processes.

What is a Concept?: The Concept as Stimulus-Class Control

Skinner defined a *concept* as a set of stimuli sharing more than one property with all members of that set controlling the same behavior (Skinner, 1974, p. 105). Conceptual control is characterized as stimulus-class control in which more than one distinctively different stimulus evokes the same operant (Lubow, 1974; Malott & Siddall, 1972; Malott, Whaley, & Malott, 1992; Mazur, 1990). For instance, a variety of chairs may evoke the tact "chair," given the appropriate educational contingencies provided by the verbal community. Conceptual control involves stimulus generalization within a stimulus class and stimulus discrimination between different classes. In other words, after some members of a stimulus class (e.g., dining chair, bar chair, and desk chair) acquire the evocative capacity over an operant (e.g., "chair"), a new, physically similar stimulus from the class (e.g., lounge chair) is likely to evoke the same operant. Simultaneously, a stimulus from another class (e.g., sofa) does not evoke the operant. From this view, the process of concept learning is analyzed as the process of establishing stimulus-class control. Our goal is to describe how a stimulus class obtains the evocative capacity.

Stimulus-class (conceptual) control can be established by reinforcing a response in the presence of members of the stimulus class and extinguishing that response in the absence of a member of that stimulus class. For instance, Herrnstein and Loveland (1964) reinforced pigeons' key pecking in the presence of pictures including human beings while extinguishing pecking in the presence of pictures not including human beings. The pigeons' differential response rate in the presence of new pictures including a human being demonstrated stimulus-class control; this is interpreted as the learning of the concept of pictures of human beings.

Many concepts are learned as a result of stimulus-class discrimination contingencies that exist in society. For example, a child may learn to say "chair" to a variety of chairs first by echoing their parent's pronunciation in the presence of a particular chair (e.g., "That is a chair, say chair") and then getting praise when he or she says "chair" in the presence of other chairs. When conceptual control is established this way, neither the child nor the parents needs to be able to state the definition of the concept (i.e., what a chair is).

Concept learning, however, might be facilitated when definitions can also be used. For instance, without using a definition of S^D, the concept of S^D might be difficult, if not impossible, to teach. If we only reinforce a tact "ess dee" to examples of S^D and extinguishing the tact to nonexamples of S^D, conceptual control may fail to be established at all, it may take a longer time, or inaccurate control may be established. In such cases, conceptual control seems to be established only through the use of definitions.

HOW TO ESTABLISH CONCEPTUAL CONTROL THROUGH DEFINITIONS: THE RULE-EXAMPLE-PRACTICE STRATEGY

Educational psychologists have developed more efficient techniques to teach concepts than the stimulus-class discrimination procedure. The rule-example-practice strategy is one of the most frequently studied and applied methods of teaching concepts (Becker & Engelmann, 1978; Engelmann & Carnine, 1982; Markle, 1990; Markle & Tiemann, 1970; McCallum, Apking & Snyder, 1987; Miller & Weaver, 1976; Tennyson & Park, 1980; Tennyson, Tennyson, & Rothen, 1980). In this strategy, the definition of a concept is presented first (rule), then examples and nonexamples of the concept follow (example), and finally discrimination tasks are presented (practice). For instance, Miller and Weaver (1976) used the rule-example-practice strategy to teach behavioral concepts such as *reinforcement, extinction, discrimination,* and *generalization.* They developed a programmed textbook in which each concept was taught with the definition and discrimination tasks. When tested with novel examples, the students who used the programmed textbook outperformed students who used a traditional textbook.

A number of laboratory experiments have shown the rule-example-practice strategy to be effective. A typical experiment consists of training and a posttest. In the training phase, subjects read the concept definition and then respond to examples and nonexamples while receiving feedback about the correctness of their responses. Usually a fixed number of tasks are provided, or the training continues until a mastery criterion is met. In the posttest, the subject is asked to select examples from novel stimuli. The percentage of correct responses from the posttest is the dependent variable. For instance, Merrill and Tennyson (1978) taught the concept of the RX_2 crystal structure of atoms using a verbal definition and graphic examples and nonexamples. In the pretest, the subjects were asked to determine if each of fifteen crystal diagrams was an example of RX_2 crystal. In the training, the subjects were given the written definition of RX_2 crystal with eight pairs of examples and nonexamples. The posttest consisted of the same discrimination tasks with 30 new diagrams.

SIMPLE VERSUS DEFINITION-BASED CONCEPTUAL CONTROL

We propose to distinguish between simple conceptual control and definition-based conceptual control. In *simple conceptual control,* members of a concept directly control an operant as a result of a stimulus-class discrimination procedure. Novel stimuli obtain evocative control because of their physical resemblance to the examples used in the stimulus-class discrimination procedure. As with Herrnstein and Loveland's (1964) pigeons, the conceptual control found in experiments with non-human subjects is of this kind. The conceptual control observed in a verbal human's everyday life such as chairs, people, and buildings are perhaps of this kind too.

The behavioral process underlying the rule-example-practice strategy is characterized as *definition-based conceptual control* because it consists of the statement of the definition and the analysis of each instance in terms of the definition. For example, in Miller and Weaver's (1976) programmed textbook, given a short story (e.g., "Every time Lisa draws a picture of flowers, George praises her"), students may covertly state the definition of reinforcement and ask themselves if the instance fits the definition (e.g., "Is the behavior more likely to occur?"). The terminal response (e.g., "That's an example of reinforcement") may be controlled not only by the instance and past reinforcement but also by these intervening verbal responses.

ROLES OF THE DEFINITION

How can the definition of the concept facilitate stimulus control by that concept? Skinner (1957, p. 360) listed three stimulus-response relations that emerge from reading or hearing a definition: (a) the statement of the concept name given the definition (naming), (b) the statement of the definition given the name of the concept (defining), and (c) the statement of the concept name given the example of the concept (identification). Chase, Johnson, and Sulzer-Azaroff (1985) added another relation to the list; (d) the generation of an example of the concept given the concept name (exemplification). Figure 1 shows these relations along with two other undefined relations. Although our focus in this paper is on conceptually-controlled identification, these other relations are also be important.

The definition might alter the function of the name and examples of the concept, emerging the stimulus-response relations

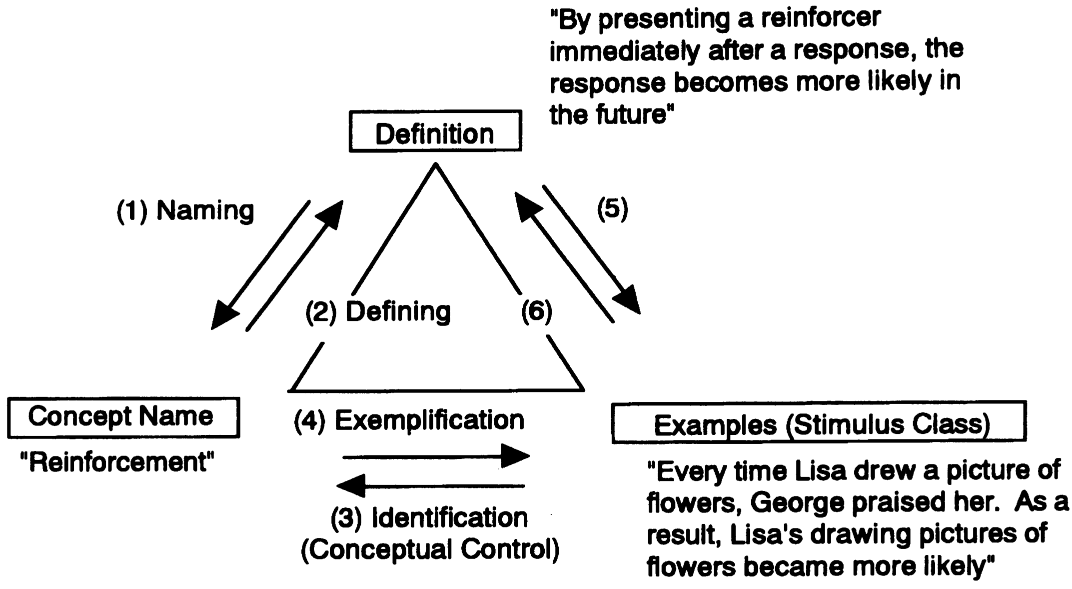

Fig. 1. Stimulus-response relations that may emerge from the concept definition.

in Figure 1. This would be in keeping with the function-altering effects attributed to verbal stimuli by Schlinger and Blakely (1987) and Schlinger (1993). For example, the rule as a description of a contingency (e.g., "push the button when you hear the buzzer to get a coin") is said to alter the evocative function of the buzzer. Given an appropriate motivating condition, the buzzer will evoke button pushing because of the prior statement of the rule. Similarly, after reading the definition of "reinforcement," the concept name ("reinforcement") may evoke a defining response ("By presenting a reinforcer..."); and each example of reinforcement may evoke the identification response ("reinforcement").

The function-altering effect of the definition of a particular concept, however, is not an innate or automatic property of the statement of the definition. A certain history of conditioning must establish such a function. Furthermore, reading or hearing a definition alone is often insufficient to produce good conceptual control. That is why rule-example-practice strategy must be added in many cases. It seems plausible that each relation in Figure 1 is reinforced by either formal or informal educational contingencies involved in learning concepts. Our next step, therefore, is to explain how the responses in those relations are evoked and reinforced.

HOW CAN DEFINITION-BASED CONCEPTUAL CONTROL BE ESTABLISHED?

During rule-example-practice training, a chain of meditating responses may be established linking the concept name, definition, and examples and nonexamples. Figure 2 illustrates simple and definition-based conceptual control with the concept of triangle. In simple conceptual control, a class of stimuli (triangles) directly controls an operant (e.g., tact). The class comes to evoke the operant through differential reinforcement. Most of us do not say the definition of triangle (i.e., "a figure that has three lines and is closed") when we say "it's a triangle." Neither do the pigeons in Herrnstein and Loveland's (1964) experiment "say" the definition of human when they peck the disk. Most conceptual control established through natural contingencies may be of this simple kind, even with

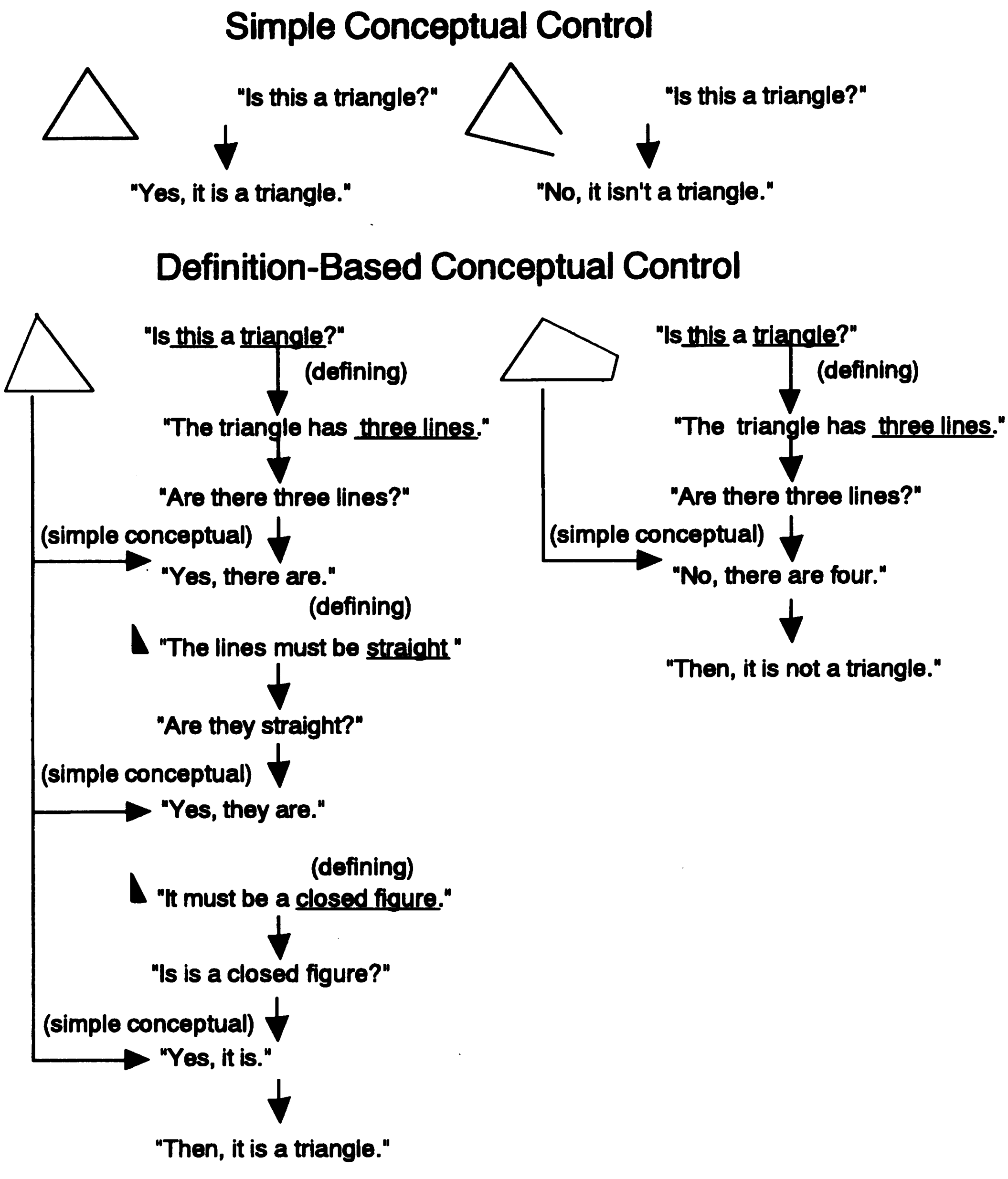

Fig. 2. An illustration of simple and definition-based conceptual control.

verbal humans. And some conceptual control established by planned educational contingencies may also be of this simple kind.

In definition-based conceptual control, it is our contention that a class of stimuli controls an operant through intervening verbal responses. Let us assume we are teaching the concept of triangle to preschool children who have not learned the concept yet. In other words, the instances of triangle do not control their behavior of saying "triangle." We might give the children a definition when they work on discrimination tasks. We can also help them to solve the problem by providing prompts such as "What is a triangle?" and "Are there three lines?" Furthermore we can ask the children to ask those questions by themselves, forming a stimulus-response chain, at the end of which the final response is emitted depending on the previous parts of the chain. The final response (i.e., "triangle" or "not triangle") is thus controlled by a combination of the sight of the geometric figure (i.e., the example) and the intervening questions and answers.

The stimulus-response chain between the first presentation of an example of a concept and a terminal response may consist of defining responses, tacts of examples, and a series of instances of simple conceptual control. In Figure 2, for example, it is assumed that the children have "learned" the concepts of *three* (numbers or counting), *straight lines*, and *closed figures*. In other words, instances of these sub-concepts must control the response directly and reliably. In practice, when the presentation of a definition does not produce accurate discrimination, we should make sure each component of the definition is controlling the relevant response.

With repeated exposures to the rule-example-practice, the instances of a concept may eventually begin to control the terminal response without the supplement of intervening verbal responses. This can be described as a transition from definition-based conceptual control to simple conceptual control. Note that in case of teaching "triangle" this certainly occurs and intervening responses will soon not be needed. According to Skinner (1974), "directions" are just a series of discriminative stimuli that evoke corresponding responses, while "instruction" is gradual fading away of the direction as the learner's responses come under the control of the natural environment. His distinction parallels our analysis of the rule-example-practice training, which may finally lead to simple conceptual control without the chain of questions and answers. Simple conceptual control, once established, would probably allow for quicker responding. In any case it is important to analyze how transition from definition-based to simple conceptual control occurs.

Once simple conceptual control has been attained, one could describe this attainment by saying the function of the sample triangle has been altered so that it now evokes the response "triangle." However, we should understand that this is a description and not an explanation. And we should be cautious in suggesting that the definition of a concept serves to alter the function of an example of that concept when such examples exert proper stimulus control only when imbedded in an elaborated stimulus-response chain involving that definition.

Some researchers maintain that we should use a mastery criterion defined in terms of fluency instead of accuracy during our concept training (Binder, 1988; Chase, Johnson, & Sulzer-Azaroff, 1985; Johnson & Chase, 1981; Lindsley, 1992). Fluency is defined in terms of speed or rate (e.g., the number of correct responses per minute). The transition from definition-based control to simple conceptual control may be facilitated by a fluency criterion. A fluency requirement should result in differential reinforcement of high rates, which in turn might reinforce attempting to identify examples while explicitly comparing it with fewer and fewer components of the definition. Research determining the variables that facilitate this kind of transition should be conducted. One question might be: "Is a fluency criterion achieved faster with or without initial definitions and with what types of concepts?"

DEFINITION-BASED CONCEPTUAL CONTROL AS PROBLEM-SOLVING

Definition-based conceptual control may be better understood as a problem-solving strategy. Problem-solving is defined as a speaker generating "stimuli to supplement other behavior already in his repertoire" (Skinner, 1957, p. 442). In definition-based conceptual control, it includes stating definitions and checking examples according to the definition. This sequence of responses can be directly taught as a strategy by providing prompts that guide the learner's responses explicitly. This could involve such devices as checklists and flowcharts. Once this general sequence of responses is acquired, one may be able to apply the sequence to novel definitions.

Research determining the extent to which this strategy generalizes to learning new concepts would be of interest.

ANALYSES OF THE PRINCIPLES OF INSTRUCTION

Educational psychologists have developed a set of principles for teaching concepts. Among them are the use of definitions, the relationship between examples and nonexamples, and the presentation order of examples in discrimination training. In this section, we will summarize several of these principles and offer an interpretation of each, using the behavior-analytic model just presented.

Principle: Use the Definition

Rationale. The presentation of the definition of a concept with its examples and nonexamples produces better performance on discrimination tasks than providing only examples and nonexamples (Tennyson & Park, 1980). Di Vesta and Peverly (1984) found that the definition is more effective when presented before discrimination training. In their study, one group of subjects read the definitions of concepts before discrimination training. Another group of subjects read the same definitions after the discrimination training. For example, *crinch* was defined as making someone angry by performing an inappropriate act. On the posttest, the subjects who received the definitions first correctly identified the new examples and nonexamples significantly more often than the subjects who received the definitions last.

Analysis. By providing a definition before discrimination training, the learner has the opportunity to practice the stimulus-response chain of questions and answers with each example and nonexample and this better prepares for the posttest. Research on schedules of reinforcement with verbal human subjects shows that subjects who receive no instruction about the contingency often state self-generated rules and follow them even if the rules do not describe the contingency correctly (Catania, Matthews, & Shimoff, 1982; Galizio, 1979). The presentation of the definition may prevent the development of incorrect self-generated definitions.

Principle: State a Definition in Terms of the Critical and Variable Attributes

Rationale. As we mentioned before, instructional designers are encouraged to state the definition of a concept as a description of its critical and variable attributes. In Di Vesta and Peverly (1984), *crinch* had two critical attributes; making someone angry, and doing so by acting inappropriately. There were some variable attributes, for instance, the situation in which crinch occurs (e.g., in a restaurant or at home).

Analysis. Perhaps definitions written in terms of critical and variable attributes are more effective because they provide more effective prompts for intervening verbal responses in definition-based conceptual control. With a list of critical attributes, a learner is more likely to ask the critical questions in the stimulus-response chain illustrated in Figure 1; and, as a result, the terminal response (i.e., discriminative response) is more reliably controlled. In the case of *crinch*, the learners can check, first, if someone gets angry and, second, if it is because of an inappropriate act, before they make the terminal response (e.g., "It's an example of crinch"). Again, notice that each component of this stimulus-response chain can consist of simple conceptual control; a number of instances of someone getting angry may directly control the learners' response. When feedback for the terminal response follows (e.g., "You're right!"), two things could happen. First, the terminal response in the presence of that specific instance is reinforced. Second, the use of the definition-based questions and answers is also reinforced. The latter might again prevent the development of an incorrect self-generated definition.

Explicitly stating a variable attribute helps when it is likely that attribute will exert inappropriate stimulus control over the behavior of the learners. For example, whether or not the recipient expresses evident satisfaction is an irrelevant or variable attribute with regard to the concept of reinforcement. Often the conceptual behavior of the learners will come under the control of such an irrelevant (variable) attribute, either because of an accidental correlation between that attribute and the examples used in the training or because of examples from the learner's daily life. Stating the irrelevance of a variable attribute allows the learner to incorporate this statement in the analytical stimulus-response chain used to classify an event as an example of the concept. This statement of irrelevance then facilitates the learner's excluding erroneous examples that might otherwise be included, and including correct examples that might otherwise be excluded.

Principle: Use of a Rational Set of Examples and Nonexamples

Rationale. Educational psychologists recommend that instructional designers should develop a rational set of examples and nonexamples for discrimination tasks. Rational sets are developed using the critical and variable attributes and have proven effective in reducing errors such as overgeneralization, undergeneralization, and misconception (Carnine, 1980a, 1980b; Di Vesta & Peverly, 1984; Granzin & Carnine, 1977; Merrill & Tennyson, 1978; Tennyson, Woolley, & Merrill, 1972; Tennyson, Steve, & Boiutwell, 1975; Williams & Carnine, 1981). *Overgeneralization* occurs when the learner identifies nonexamples as examples; *undergeneralization* occurs when the learner identifies examples as nonexamples; and *misconception* occurs when the learner both identifies examples as nonexamples and nonexamples as examples (Merrill & Tennyson, 1978; Tennyson & Park, 1980; Tiemann & Markle, 1990). A rational set of nonexamples consists of nonexamples each of which lacks only one of the critical attributes. Each nonexample is then paired with the example that has the same critical and variable attributes except for the one critical attribute that nonexample lacks. This is called the minimally different pair of example and nonexample (Carnine, 1980b; Granzin & Carnine, 1977; Williams & Carnine, 1981). The number of the minimally different pairs equals the number of the critical attributes of the concept and the pairs "demonstrate to a learner what the concept does not include" (Tiemann & Markle, 1990, p. 120). Similarly, a rational set of examples consists of examples each of which satisfies all the critical attributes and diverges on a variable attribute. The presentation of examples with divergent variable attributes demonstrates "what the concept does include" (Tiemann & Markle, 1990, p. 120).

Analysis. The minimally different pairs of examples and nonexamples expose the learner to all the critical attributes. Given a definition describing the critical attributes of a concept and a minimally different pair, the intervening responses and terminal response are emitted based on the definition (see Figure 1). Because a rational set includes all critical attributes, the learner must identify all of them when engaging in discrimination tasks. In other words, all the components of the stimulus-response chain, each of which may represent simple conceptual control, have a chance to be evoked and reinforced.

The use of all minimally different pairs may ensure that all critical attributes come to control the learner's behavior. If nonexamples differ from their paired examples in more than one critical attribute, discriminative responses may not come under the control of all the critical attributes because being controlled by only one missing critical attribute is enough for successful discrimination. This can happen in both simple and definition-based conceptual control. When compound stimuli are used in discrimination training with one element being sufficient, little or no conditioning often occurs to the other element. This phenomenon is called *blocking* and found in experiments with non-human subjects' respondent relations (Mazur, 1990, chap. 5) and with mentally retarded children's operant stimulus discrimination (Singh & Solman, 1990). In simple conceptual control, the arrangement of minimally different pairs could prevent such blocking effects. For instance, if open figures with four lines are used as nonexamples in discrimination training of triangle with pigeons, their discriminative response may come under control of *closed figures* but not *three lines,* and the pigeon may respond to closed squares as triangle. In definition-based conceptual control, learners may never state the relevant part of the definition and may never count the number of lines during discrimination training. Thus, that part of stimulus-response chain may never be reinforced.

The minimally different pairs may also prevent the learners from forming incorrect definitions. If a nonexample has a different set of variable attributes than the paired example, it becomes possible for the learner to discriminate the example not by the critical attribute but by the irrelevant variable attributes. For instance, if an example of crinch was illustrated in a restaurant and its paired nonexample in a train, the learner may respond "it's a crinch" to whatever is happening in a restaurant (i.e., a variable attribute). The learner may generate a new definition and use it. This would happen more frequently when the definition is not provided. Such errors can be maintained when the learner's response controlled by incorrect definitions results in intermittent reinforcement. With the minimally different pairs, responses controlled by incorrect definitions are never reinforced.

Moreover, the use of the minimally different pairs may help the learner form an *autoclitic frame.* An *autoclitic frame* is a statement in the form of "If X, then Y" (Alessi, 1987; Skinner, 1957, p. 359). For instance, the learner may restate the definition of crinch as "If nobody gets angry, I should say it is not crinch" and "If nobody acts inappropriately, it is not crinch." Such verbal responses may produce more effective discriminative stimuli than a mere definition. Therefore, they are immediately useful in discrimination training with minimally different pairs. Consequently, the statement of the definition is reinforced, and the frequency of stating definitions in more effective autoclitic frames may be increased. This may be an important problem-solving skill in concept learning. Although repeated use of a standard definition may well be sufficient, effects of training on converting a definition to an autoclitic frame should be empirically examined in search of more efficient teaching techniques.

Principle: Present Coordinate Concepts Simultaneously

Rationale. Many concepts are related to other concepts, and related concepts should often be taught together. The relationships between concepts can be described as superordinate, subordinate, and coordinate (Tiemann & Markle, 1990). For instance, *reinforcement* is subordinate to *contingency* because it is one of many contingencies, and *contingency* is superordinate to *reinforcement.* One step lower in the hierarchy, *reinforcement* is superordinate to *continuous reinforcement* and *intermittent reinforcement.* Coordinate concepts are examples of the same superordinate concept but are not subordinate or superordinate to each other. *Reinforcement, escape, punishment,* and *penalty* are coordinate concepts, all of which are examples of the same superordinate concept, *contingency.* In coordinate concepts, a nonexample of one concept is an example of another concept, which Tiemann and Markle (1990) named *multiple discrimination.* A few variables have proven helpful in improving instruction with multiple discriminations.

Coordinate concepts are taught effectively when examples from each concept are presented successively (Tennyson & Park, 1980). For instance, Tennyson, Tennyson, and Rothen (1980) compared three presentation orders in teaching the four contingencies mentioned above. In their experiment, the subjects took a pretest, received a written definition of the contingencies, worked on the learning program, and took a posttest. In the learning program, each group received discrimination tasks in different orders. In the simultaneous presentation group, the four concepts were presented at the same time with one example from each concept in a rational set. Within a rational set, the examples had the same variable attributes and different critical attributes, whereas between rational sets the examples had divergent variable attributes. Each example was presented randomly within a rational set. In the collective presentation group, the examples of *reinforcement* and *escape* were presented in the first half and the examples of *punishment* and *penalty* were presented in the second half. In the successive presentation group, the examples were grouped and presented in order of *reinforcement, escape, punishment,* and *penalty.* The subjects in the simultaneous presentation group performed significantly better in the posttest than the subjects in the other groups. The authors' interpretation of the results, however, was cognitive: They maintained that by simultaneously presenting all coordinate concepts "the whole structure related contextually to the concept is activated and becomes available to attention" (Tennyson et al., 1980, p. 500).

Analysis. The result of Tennyson et al. (1980) may be interpreted more behaviorally. In the simultaneous presentation, the examples of each concept actually function as minimally different nonexamples of other concepts, and they were presented within four consecutive trials. As we discussed above, this procedure forced the subjects to read the definition each time and to check the relevant part of the definition to determine which contingency an example represented. Thus, compared to the subjects in the other two groups, the subjects in this group may have read and used the entire definition more frequently and thus received more reinforced trials. Moreover, because minimally different examples and nonexamples were presented temporally closer to each other, the differences in critical attributes may have been a more effective discriminative stimulus. In other words, the subject's observation of the differences was more likely reinforced. If so, this principle could be applied to non-verbal subject's concept learning. However, we found no experiments with non-verbal subjects that investigated this issue. Further analysis is needed.

Principle: Present the Next Instance Based on the Learner's Previous Error

Rationale. The presentation order of examples based on the learner's most recent error produces significantly better performance than a random presentation independent of errors (Burts, McKinney, Gilmore, & Ford, 1985; Park & Tennyson, 1986). For instance, Burts et al. (1985) compared the response-sensitive strategy and a random presentation of examples during discrimination training of four geographic concepts including *mountains, hills, tablelands,* and *plains.* In the response-sensitive strategy, when the subject made an incorrect answer, the next example was selected from the pool of examples of the concept to which the error was made. For instance, when the subject said "hills" to a picture of tablelands, then a picture of hills was presented next. When the subject made a correct answer, the next example was randomly selected. The response-sensitive strategy is believed to be effective because it facilitates discrimination learning between confusing concepts (Tennyson & Park, 1980).

Analysis. The response-sensitive strategy might be effective for the following reasons. By presenting "confusing" concepts temporally closer, the difference in the critical attribute becomes a more effective discriminative stimulus. Simultaneous discrimination (an example and a nonexample are presented as a pair) may be easier than successive discrimination (either example or nonexample is presented one at a time). The difference between the examples is more likely to evoke an appropriate set of responses such as reading the corresponding part of the definition (i.e., the critical attribute in question) and inspecting the example about that critical attribute. For instance, the subject who just made an error "hills" to an example of tablelands is more likely to respond to a critical attribute in the example of hills presented immediately after the error. The subject might say to himself, "I see, hills must have a peak and are not flat like tablelands are." Perhaps the subject is more likely to ask himself if a picture has a peak from then on.

Finally, making mistakes may work as a strong establishing operation for "knowing" what was wrong. In the learner's educational history, a repeated mistake may be associated with punishment. Thus, a mistake may serve as a discriminative stimulus in the presence of which the same mistake will be punished. "Knowing" what was wrong would help to avoid such an aversive condition. Thus, closer inspection of the next example, using of the stimulus-response chain in Figure 1, is evoked and reinforced. Our analysis of this principle suggests it may be more relevant to the establishment of definition-based conceptual control than simple conceptual control.

CONCLUSION

We have attempted to analyze two kinds of processes that may underlie concept learning: simple conceptual control and definition-based conceptual control. In doing so, we have made use of only basic behavioral principles, though much of the research relevant to definition-based conceptual control comes from a more cognitive orientation. This is a first step in the development of a behavior-analytic framework that encompasses a wider range of research than has typically been the case. In so doing, we hope to have introduced behavior-analytic readers to a body of relevant research on concept training and educational technology. A behavioral interpretation of this research suggests that we might further study and apply an explicit stimulus-response-chain approach to definition-based concept learning and general conceptual problem solving.

There are some merits in analyzing the work of other areas in terms of behavioral principles. First, we can reorganize the literature and topics from a behavioral perspective so that further research can be conducted theoretically as well as experimentally. Second, the variables that have received little attention by most behavior analysts (e.g., the characteristics of definitions, the arrangement of examples and nonexamples, presentation order, etc.) may receive more attention. For instance, the concepts of the critical and variable attributes and the minimally different pairs of examples and nonexamples have not seemed to emerge from the view point that considers concept learning as simple stimulus-class discrimination.

Finally, we may help to improve teaching techniques by analyzing already existing data and/or conducting new research. Research and practices in direct-instruction and precision teaching seem promising, and we should be able to offer more. In this paper we analyzed how we might be able to facilitate the transition from definition-based to simple conceptual control. Research examining this topic using fluency training will be valuable. Also more direct teaching of problem-solving methods that enhance definition-based control or increase the function altering effects of the concept definition will be appreciated too.

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